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ABSTRACT

The primary goal of the conference panel on modeling the reading process was to prepare a programatically related set of suggestions which could lead to a clearer account of reading and to an ability to pose successively better research questions. This panel report contains sections on the development of a model for word recognition during reading, an investigation of the integration of word meanings into higher order structures, the characterization of the development of reading ability in children, the development of a model for eye movement guidance during reading, and a measurement of the information processing habits of competent readers when they are confronted with complex reading tasks. A list of references is included. (JM)

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modeling the reading process

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CONFERENCE ON STUDIES IN READING

"It was unlawful, as well as unsafe, to teach a slave to read.
'It will forever unfit him to be a slave. He will at once become unmanageable and of no value to his master.'
These words sank deep into my heart. From that moment, I understood the pathway from slavery to freedom. Though conscious of the difficulty of learning without a teacher, I set out with high hope and fixed purpose, at whatever cost of trouble, to learn how to read."

Frederick Douglass

NATIONAL INSTITUTE OF EDUCATION

Washington, D.C.
June, 1975

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WASHINGTON, D.C.

JUNE, 1975

[WORKING DRAFT]

NIE CONFERENCE ON STUDIES IN READING

PANEL 4

MODELING THE READING PROCESS

PROBLEM STATEMENT

Collect and synthesize experimental data and theoretical notions on reading into one or more process-oriented models and generate from these models hypotheses to test.

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PANEL 4

MODELING THE READING PROCESS

TABLE OF CONTENTS

	PAGE
PREFACE	iii
INTRODUCTION	1
Work Plan	1
Models	1
On Relevance	2
Reading Undefined	2
Issues and Priorities	3
APPROACH 4.1: DEVELOPMENT OF A MODEL FOR WORD RECOGNITION DURING READING	4
Program 4.1.1: Determination of the amount of accurate information for word recognition obtained from words present in peripheral vision	4
Program 4.1.2: Determination of what visual information in the letter string the reader uses in word recognition	5
Program 4.1.3: Determination of how orthographic structure facilitates word recognition	5
Program 4.1.4: Determination of how syntactic and semantic context contribute to word recognition	5
Program 4.1.5: Determination of whether phonological mediation is necessary for word recognition	6
Program 4.1.6: Determination of what kind of long-term memory storage units are necessary in letter and word recognition	6
APPROACH 4.2: INVESTIGATION OF THE INTEGRATION OF WORD MEANINGS INTO HIGHER ORDER STRUCTURES	7
Program 4.2.1: Determination of how the reader integrates word meanings into higher order semantic structures	7
Program 4.2.2: Determination of the temporal course of comprehension in reading	8
Program 4.2.3: Determination of what role inner speech plays in reading	8
APPROACH 4.3: CHARACTERIZATION OF THE DEVELOPMENT OF READING ABILITY IN CHILDREN	9
Program 4.3.1: Empirical verification of which of the methods used in determining reading processes in adults are valid for children	10

Program 4.3.2: Determination of which of the components of the reading process postulated for skilled adult readers are operative in children 10
Program 4.3.3: Examination of the role of instructional histories in the development of children's reading skills 10
Program 4.3.4: Identification of the differences between good and poor readers with respect to processing components 11
Program 4.3.5: Examination of those behaviors observed in the learner but not generally observed in skilled readers 11

APPROACH 4.4: DEVELOPMENT OF A MODEL FOR EYE-MOVEMENT GUIDANCE DURING READING 12

Program 4.4.1: Determination of how accurately the eyes can be moved in a saccade 13
Program 4.4.2: Determination of how long subjects need to integrate visually presented information and move their eyes on the basis of that information 13
Program 4.4.3: Determination of what types of information can be resolved at different points in the periphery 13
Program 4.4.4: Determination of how much visual information can be resolved in the periphery with unlimited processing time 14
Program 4.4.5: Determination of how much information about the spatial properties of the text is available to readers for guiding regressive movements 14
Program 4.4.6: Determination of whether, as the guidance model assumes, readers can resolve meaning and simultaneously decide where to go next 14

APPROACH 4.5: MEASUREMENT OF THE INFORMATION-PROCESSING HABITS OF COMPETENT READERS WHEN THEY ARE CONFRONTED WITH COMPLEX READING TASKS 16

Program 4.5.1: Development of a measure of information load for short texts 17
Program 4.5.2: Development of eye-movement tracking procedures for careful reading 17
Program 4.5.3: Collection of baseline data on silent reading rates for careful reading under varying information load and recall conditions and for extent of recall for single pass reading under conditions of varying information load 17
Program 4.5.4: Measurement of reading behavior for texts of varying information load and for varying required recall criteria 17
Program 4.5.5: Determination of the accuracy with which readers can return to previously read materials in the immediate reading task 18
Program 4.5.6: Determination of the effect on accuracy of recalling nonverbal information in a text 18

PREFACE

The National Institute of Education (NIE) came into being during 1972. Its authorizing legislation requires the NIE to:

- Help solve or alleviate the problems of, and achieve the objectives of, American Education.
- Advance the practice of education as an art, science, and profession.
- Strengthen the scientific and technological foundations of education.
- Build an effective education research and development system.

In order to aid in meeting these general objectives, the National Council on Education Research (NIE's policymaking body) approved the creation of five priority programs in December, 1973. One of the priority programs was Essential Skills.* Its purpose was:

> To investigate through research and development, ways to aid all children to obtain skills essential for functioning adequately in school and society.

The initial focus of the Essential Skills Program was in the area of reading. Broad guidelines for an NIE effort in reading had been developed in a small conference held on Cape Cod during the late summer of 1973.** During 1974, the Essential Skills Program carried out an intensive effort designed to formulate more specific plans for funding research and development activities in reading. A variety of meetings were held with groups of teachers, school administrators, and scientists to designate directions for the program. The most ambitious of the meetings was held in Washington, D.C., in August, 1974, and directly involved over 175 individuals -- 50 as Conference participants and 125 as consultants to the Conference. This report is the product of one of the 10 panels of the August Conference.

The impetus for the Conference stemmed from a number of concerns about the state of Federal funding of research and development in education. Four concerns stood out in particular for reading.

1. Research in the field of reading was fragmented and noncumulative.

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*During the past few months, the Essential Skills Program has been renamed the Learning Division of the Basic Skills Group. Both the Basic Skills Group and the Learning Division continue to follow the guidelines set out by the National Council in December, 1973 (above).

**See Miller, George A. (ed.) Linguistic Communication: Perspective for Research, International Reading Association; Newark, Delaware, 1974, 45 pp.

2. The Federal Government was not making constructive use of the state of knowledge in the field in their decisions to fund new research and development.

3. There was a lack of positive and firm coordination between the Federal Government and the professional research and practitioner organizations around the country.

4. A large number of scientists in a variety of disciplines carry out research with relevance to reading. We considered it important to attract these scientists to work in the applied areas of educational research.

The Conference itself was a step in meeting these concerns. During the past year, the NIE has been developing plans for funding research and development in reading for the next two years. Suggestions from the Conference have played an important role in this process. But planning is an ongoing process and we hope by publishing and widely disseminating the reports from the Conference to stimulate discussion of the reports, of research and development in the field of reading, and, indirectly, of the plans of the Institute.

To some extent the format for the Conference was influenced by three other similar efforts of the Federal Government. In the area of health research, the conferences leading to the National Cancer Plan and the National Heart and Lung Institute Plan served as partial models. Within NIE, the Teaching Division had held a major planning effort in the area of teaching research during the early summer of 1974. The intent in each of these efforts was to develop a coherent set of documents that would be responsive to the needs of the American public and to knowledge in the field.

We felt it necessary to structure the Conference in two important ways. First, after extensive consultation with scientists and practitioners in the field we arrived at the conclusion that major efforts in the past had often ignored or down-played the critical importance of the stage of reading called "reading comprehension." Although we realized the impossibility of actually separating out "reading comprehension" from the earlier stage of learning to read -- which requires the learner to be able to translate written letters and words into speech -- our advice suggested that the comprehension or "reading for meaning" stage required far more attention than it had received in the past. Consequently, seven of the ten panels focused on problems in this area. Second, to direct the focus of the panels to planning future research we requested the panelists to organize their ideas into general approaches within the problem area, within the approaches to suggest programs for research, and, finally, when possible to specify particular research or development projects.

The seven panels addressing problems in comprehension spanned a wide range of concerns. The first three panels focused on basic research issues. Their panel reports are titled: Semantics, Concepts, and Culture; The Structure and Use of Language; and Attention and Motivation. The fourth panel was asked to consider the problem of Modeling the Reading Process. The fifth panel directed its attention to the issue of measuring how well people read and its report is titled Assessment of Reading Comprehension. The sixth and seventh reports directed themselves respectively at the practical problems of the Application of Existing Reading Comprehension Research and Reading Comprehension and the High School Graduate. The final three panels directed their attention to three pressing concerns in early reading: Learning and Motivation in Early Reading; Reading Strategies for Different Cultural and Linguistic Groups; and Essential Skills and Skill Hierarchies in Reading.

Although the reports have undergone some revision and editing since the Conference, the major part of the work was done in concentrated sessions in the space of a few days. The resulting documents are not polished or exhaustive. They are meant to be working documents to stimulate debate, suggestions, and comments. Such comments or requests for other reports should be directed to:

Director, Learning Division
National Institute of Education
Washington, D.C. 20208

The work of organizing the Conference was carried out by members of the Essential Skills staff at the NIE -- each of the panels had an NIE staff person as a permanent liaison. Special acknowledgments are due to Susan Duffy and Donald Fisher for their assistance in preparing the reports for publication and to Arthur Young & Company for coordination and arrangements before, during, and after the Conference. Finally, the work of NIE cannot proceed without the kind of skill, involvement, and hard work given by the panel chairpeople, panelists, and consultants for this Conference. The ideas and emphases in the reports are the products of their cumulative expertise.

Marshall S. Smith
Conference Chairperson

LIST OF PANEL REPORTS AND CHAIRPERSONS

1. Semantics, Concepts, and Culture, Dr. George Miller, Rockefeller University

2. The Structure and Use of Language, Dr. Thomas Trabasso, Princeton University

3. Attention and Motivation, Dr. Sheldon White, Harvard University

4. Modeling the Reading Process, Dr. Richard Venezky, Wisconsin University

5. Assessment of Reading Comprehension, Dr. Ernst Rothkopf, Bell Laboratories

6. Application of Existing Reading Comprehension Research, Dr. Lauren Resnick, University of Pittsburgh

7. Reading Comprehension and the High School Graduate, Dr. Mina Shaugnessy, City University of New York

8. Learning and Motivation in Early Reading, Dr. Richard Hodges, University of Chicago

9. Reading Strategies for Different Cultural and Linguistic Groups, Dr. Manuel Ramirez, University of California, Santa Cruz

10. Essential Skills and Skill Hierarchies in Reading, Dr. Irene Athey, University of Rochester

PANEL 4

MODELING THE READING PROCESS

INTRODUCTION

The goal of this report is to suggest studies that will lead to a better understanding of the processes involved in reading. Although the organizing principle of our recommendations is an information-processing model, we have included in the scope of our concern a broad range of experimental studies that could produce information for a variety of different approaches to modeling. Our primary goal was to prepare a programmatically related set of suggestions which could lead cumulatively to a clearer account of reading, or at least to an ability to pose successively better research questions. The following sections define the various assumptions under which we operated, and they are followed by recommendations.

Work Plan

The recommendations presented here are the result of nearly 4 months of work by the panel members. We sent a form letter to approximately 100 researchers and educators who have published on reading or reading-related work, requesting information on their current research and soliciting their opinions on an initial draft of the panel's work plan. We received about 50 replies, including reprints and personal comments. We also held meetings and phone conversations with a number of researchers to explore their work and their recommendations in detail. Their expertise was important in guiding our attention to current research and in revealing the depth of interest, especially among experimental psychologists, in reading-related research. We invited several persons to submit research recommendations on specific topic areas. These reports will be available as a separate appendix to this report.

The three panel members met prior to the planning conference, and worked together at the conference and afterward to produce the present draft. We considered, but did not include in the recommendations presented here, reviews of extensive background material, questions, and syntheses, which guided the selection of topics discussed here. Such issues as the dependence of letter and word recognition upon retinal location, the validity of phonemic encoding models for word recognition, and the methodological problems in distinguishing parallel from serial processing, for example, occupied a considerable amount of our time, yet are only implicitly contained in this report.

Models

A good model is one which organizes complex and seemingly unrelated data in an interesting manner, and which generates testable hypotheses. In this sense, a good model for a reading process is one that reveals its limitations in a hurry, that is, leads to experiments which themselves produce data for building an improved model. In this regard we are following the opinions of Kleene (1952), Popper (1959), and Kaplan (1964).

The types of models we endorse are those positing component processes or stages (but not necessarily discrete stages) and attempting to describe the forms of information involved with each stage. Models that are so general in their descriptions or so vague in their inner workings that no interesting hypotheses can be generated from them for experimental testing, while they may have pedagogical or other applications, are of no value for the experimental work proposed here.

The absence here of any discussion of the complete models for the reading process published in the last 10 years is intentional. After extensive analysis of such models, we believe that we know too little about the various components of the reading process to justify attention to complete models. Where we appear to have made advances in understanding the reading process, they come from narrowly delimited areas in which we can easily construct and test models.

On Relevance

The recommendations of this panel are an attempt to gain through systematic and precise means an understanding of fundamental processes and relationships. This goal is justified on two grounds. First, an understanding of the fundamental processes in reading is essential for evaluating current teaching and testing practices. Second, such understanding can also lead to the construction of improved strategies for diagnosis and intervention. Our present ability to isolate causes of reading failure is limited to the assessment of differences in behavior--blending, word recognition, getting the main idea, and so on. In spite of some suggestive notions from developmental psychologists, we have been able neither to isolate fundamental processes distinguishing good from poor readers, nor to explain the abnormal rate of learning of some children. A processing model, in its attempt to define operations and relationships between components in testable terms, allows the definition of potential points for diagnosis. Whereas methods of diagnosis and instructional intervention would remain to be determined experimentally, the study of component processes in reading can serve as a foundation for such practical research.

Reading--Undefined

Because the goal of the work we propose is to define component processes in reading, we find little use for any of the conventional definitions of reading which presuppose particular reading processes, e.g., translation from writing to meaning or translation from writing to inner speech. Instead, we propose to start with observed behaviors of the skilled reader, and to continue from there by experimental means in an attempt to infer component psychological processes. The resulting model or models for these processes become their definitional mechanisms. The problem of defining types of reading behavior is addressed specifically in Approach 4.5.

Issues and Priorities

The recommendations that follow are aimed at resolving fundamental issues in the understanding of reading processes and, as such, should receive a high priority in the funding of basic research. With respect to funding priorities across issues, the Panel suggests that all research proposals attending to these issues be considered on the basis of quality and imagination. However, two approaches deserve special attention: Approach 4.1, Development of a Model for Word Recognition During Reading, could show major results in a short time with a minimal allocation of new funding. It has already attracted the interests of a large number of competent psychologists. Approach 4.3, Characterization of the Development of Reading Ability in Children, is a crucial concern for the design and evaluation of both instruction and diagnosis, but as yet has received little systematic attention from psychologists or educators. Proposals attending to basic methodological issues in this latter area should be encouraged.

APPROACH 4.1

DEVELOPMENT OF A MODEL FOR WORD RECOGNITION DURING READING

Studies on word recognition comprise the major portion of the experimental literature related to reading. Controversies over the features and processes by which readers recognize words attest to the continuing vitality of the reading issue in experimental psychology. We can review the history and current status of these controversies in Huey (1908), Woodworth (1938), Smith and Spoehr (1974), Massaro (in press), and Gibson and Levin (1975).

From this literature the following questions emerge:

(a) What role does peripheral vision play in word recognition?

(b) What visual information in the letter string does the reader use for word recognition (e.g., word shape, feature sets of letters, feature sets of words)?

(c) How does orthographic structure contribute to recognition?

(d) How does syntactic or semantic context contribute to recognition?

(e) Is phonological mediation required for word recognition?

(f) What kind of long-term memory storage units are necessary in word and letter recognition?

Program 4.1.1 Determination of the Amount of Accurate Information for Word Recognition Obtained from Words Present in Peripheral Vision.

The majority of the recent work on word recognition has involved brief exposures of isolated words in foveal vision. However, in reading, individuals move their eyes to words generally first encountered in peripheral vision. Does the presence of the word in peripheral vision facilitate its recognition when the eye jumps to it? The following study addresses this question. Subjects first fixate on a point while a word is presented in peripheral vision. Subjects are then instructed to fixate on the word itself. When they do so, it is masked, as in tachistoscopic experiments. This case is compared with the case in which subjects are presented with a point rather than a word in the periphery. Subjects are then instructed to fixate on the point itself. The test word is presented at this point while the subjects are moving their eyes. When they have fixated on the word, it is then masked as in the first case. Since subjects

in the second case have not had the test words in their periphery, while subjects in the first case have, the study should give information about the importance of peripheral vision to word recognition.

Program 4.1.2 Determination of What Visual Information in the Letter String the Reader Uses in Word Recognition.

We need research to determine which visual features contribute to word recognition in continuous, "natural" reading. For example, given a typical type-font of beginning reading texts, confusion errors, similarity ratings, and multidimensional scaling procedures can be used to isolate these features. Bouma (1971) has had considerable success in isolating the visual features in IBM Courier 10 type-font. We should explore new approaches to this particular problem. See, for example, Rumelhart's study (1971) with an artificial type-font for a promising approach.

Program 4.1.3 Determination of How Orthographic Structure Facilitates Word Recognition.

Two mechanisms have been proposed to account for the use of orthographic structure in reading. The first assumes that readers store specific information about spelling units (words), that is to say, they retain each spelling pattern in long-term memory. The second mechanism assumes that readers use rules dynamically for combining letters. A central concern should be with innovative work that not only distinguishes between these two theories, but draws its hypotheses from a thorough analysis of the orthographic structure of English words and their occurrences in texts.

Program 4.1.4 Determination of How Syntactic and Semantic Context Contribute to Word Recognition.

An information-processing approach to reading requires that various stages of processing be isolated and that the forms of information coming in and going out of each be specified. For the most part, the experiments that have demonstrated the effect of semantic and syntactic context in reading have not been precise enough to identify which processing stage is facilitated, e.g., the stage of simple recognition of the word or the stage of its incorporation into immediate memory. The latter stage involves an integrative task permitting short-term recall of the word, while the former stage does not. It is certainly possible that different coding contexts (different texts, different demands on the reader, etc.) will facilitate one or the other or both of these processes. In this case, the development of a partial model allowing us to determine when and how the processes are influenced would be called for.

Program 4.1.5 Determination of Whether Phonological Mediation is Necessary for Word Recognition.

A number of investigators have proposed that phonological mediation is necessary for word recognition and experimental tests of this hypothesis are being carried out. However, we need experiments to determine whether phonological mediation is necessary in natural reading situations, not just whether it might occur in a particular experimental task. We must know the conditions, if any, which lead the reader to use phonological mediation in deriving meaning from text.

Program 4.1.6 Determination of What Kind of Long-Term Memory Storage Units are Necessary in Letter and Word Recognition.

Consider the well-known findings, since the time of Cattell, that a reader can recognize a word as easily as a single letter. To explain this finding, models have proposed hierarchically structured storage units corresponding to letter features, spelling patterns, and words (e.g., Estes, in preparation, LaBerge and Samuels, 1974). We need experiments to define more explicitly the nature of these processes.

APPROACH 4.2

INVESTIGATION OF THE INTEGRATION OF WORD MEANINGS INTO HIGHER ORDER STRUCTURES

In the information-processing approach that we have proposed, reading involves the successive recognition of larger and more abstract meanings. How does the reader go from the recognition of word meaning to the recognition of the meaning of phrases, sentences, and stories? Panels 1 and 2 are concerned with this problem, so we refer the reader to those reports for detailed research proposals. Here we delineate some critical issues as they relate to an information-processing approach. However, we are far less confident in our ability to posit relevant questions in this area than we are in the area of eye movements and word recognition, where the procedures and knowledge base are sufficiently well-developed to allow a clearer definition of issues. Readers have available for comprehending a text, a complete store of knowledge and experience built up over a lifetime. They also appear to have a variety of strategies to apply in obtaining and retaining meaning. We are only now beginning to find promising models for the information content of texts or conversations, and for the ways in which people store information in long-term memory.

The temporary storage structures available in reading provide a critical limitation on the processing of sentence and paragraph meaning. Clearly, we need research aimed at defining these limitations in adult and child readers. How soon does the integration of word meaning occur after word recognition and to what extent do semantic structures contribute to the integration of meaning? What representation of sentence and text meaning is most appropriate for the on-line processing of phrase, sentence, and text meaning? How does subvocalization or phonological translation contribute to the integration of word meaning across sentence and storage units?

Program 4.2.1 Determination of How the Reader Integrates Word Meanings into Higher Order Semantic Structures.

Smith (1971), influenced by the work of Miller (1962), proposed that higher order meaning units are recognized as wholes in a direct, nonmediated feature-to-meaning correspondence. However, it seems unlikely that higher order meaning units such as sentences can be recognized in this way. Speech perception work by Bever and his colleagues (Bever, Lackner, and Kirk, 1969) has shown that higher order syntactic and semantic processing must occur after word recognition, that is, after word meaning is derived. Similar work should be carried out using written language.

Program 4.2.2 Determination of the Temporal Course of Comprehension in Reading.

A variety of different paradigms have been used in recent years to explore the temporal course of sentence comprehension. Aaronson's and Shapiro's (n.d.) subjects, for example, control the presentation rate of successive words in a printed sentence. The recorded exposure times related to higher level grammatical units when the subjects were reading for verbatim recall, but did not vary with grammatical structure when they were reading only for comprehension. Isakson (1974) employed a task in which subjects had to detect an auditory signal while reading a sentence. He found that reaction times increased at points where a case structure model would predict the termination of a semantic unit. Phoneme monitoring tasks (Fodor, Bever, and Garrett, 1974) have been used successfully in exploring semantic and syntactic processing in listening. Parallel tasks for reading comprehension may be equally profitable (Corcoran, 1966; Cohen, 1970). Continued investigation and integration of work in these areas seems necessary both for the development of a valid model of reading and for the eventual understanding of how to develop more readable materials.

Program 4.2.3 Determination of What Role Inner Speech Plays in Reading.

Studies by Hardyck and Petrinovich (1970) and by McGuigan and Rodier (1968) have shown that subvocalization increases when the perceptual or cognitive load in reading increases. Cleland (1971) suggests that subvocalization is tied to reading speed and has demonstrated such an effect in one experiment. Erickson, Mattingly, and Turvey (1973) showed that phonological translation influenced immediate memory for characters in Japanese Kanji. Before we can interpret fully any of these results, we must resolve two basic questions: Do subvocalizations which occur during reading consist of inner pronunciations of the words being read, or are they noise? At what stage of information processing does subvocalization occur?

APPROACH 4.3

CHARACTERIZATION OF THE DEVELOPMENT OF
READING ABILITY IN CHILDREN

From the time children begin to demonstrate rudimentary reading skills to the time they may be considered proficient, adultlike readers, they may go through a number of stages characterized by processes which differ from those postulated for adult readers. On the other hand, children may function, according to the same processes, with variation in performance ascribable to differences in degree of competence, e.g., speed, timing, or size of vocabulary. Conceptualizations of children's reading must resolve by empirical means the question of the degree to which these alternatives come into play. This is one major requirement of developmental studies.

A second and equally provocative requirement is to characterize the dynamics of transition: How do changes occur? This issue is relevant to whether children's reading processes vary in kind or degree. If different processing stages occur in development, one must account for how children proceed from one processing stage to another. We understand that these issues constitute the crux of developmental psychology and as such are not amenable to easy answers. It is imperative, nevertheless, that reading research address these questions systematically.

There have been few attempts to construct models that would account for the development of eye movements, word recognition, and integration skills that fluent readers evidence. One notable exception is the work of Gibson and her colleagues who relate the acquisition of reading skills to a theory of perceptual learning (Gibson and Levin, 1975). To construct a model for a child who has had 4 years of reading experience would require knowledge not yet available on the cognition, memory, and language processing of children. In fact, the literature sorely neglects these topics, particularly for the ages from 8 to 12. How these capacities might be marshaled by children in learning and refining reading skills remains elusive. Adults' progress in learning to read is not suggestive, since here the observations have been only anecdotal.

Given these reservations, we have concentrated our recommendations on studies of the reading processes of skilled readers. A set of recommendations related to developmental models follows, but these recommendations concern for the most part the gathering of basic information from which developmental questions could be derived.

Program 4.3.1 Empirical Verification of Which of the Methods Used in Determining Reading Processes in Adults Are Valid for Children.

Such an effort would be useful not only for characterizing reading development but also for comparing groups with respect to instructional methods and success in learning. The methods which should be investigated include techniques for studying eye movements, oral introspection, memory recall paradigms, and the use of mutilated text.

Program 4.3.2 Determination of Which of the Components of the Reading Process Postulated for Skilled Adult Readers Are Operative in Children.

Of particular interest are the accuracy of regressive eye movements, the use of orthographic and syntactic or semantic context in word recognition, and the temporal course of integration of word meanings into higher semantic units. Studies by Marcel (in press) and by Golinkoff (1974) have already addressed some of these issues.

Program 4.3.3 Examination of the Role of Instructional Histories in the Development of Children's Reading Skills.

It is worth considering whether or not we can regard learning to read as independent of instruction. The developmental view that emphasizes cognitive and linguistic growth depending on internal maturation and rule construction (Moore, 1973) would suggest that specific sorts of instruction influence learning to read in only a remote way. The fact that some children learn the basics of reading with no formal instruction at all would support this view, but the fact that other healthy children avoid or postpone learning to read makes it clear that any such development may not be inevitable. The research background is equivocal and limited on this issue. Comparisons of the effectiveness of reading methods discriminate among groups of children in minor ways which tend to wash out after the first several years of reading experience. Similarly, the method of comparing errors that children make in reading texts has not always brought sufficient refinement or perspective to the issue. For example, Weber (1970) shows essentially no differences between two first-grade classes which received different reading instruction on measures of the graphic similarity and syntactic acceptability of their errors, whereas Barr (1972) shows differences in graphic similarity when children are taught sets of words through two different training procedures. One potentially powerful approach would be to study word recognition and the use of orthographic and syntactic or semantic context as a function of the type of reading instruction. Promising developmental work showing that children are aware of letter strings that conform to English orthographic patterns by second or third grade has been done by Rosinski and Wheeler (1972). Now it is necessary to show that children at these same grade levels use this information in reading. One strategy is to match readers who have

received different initial reading instruction on the basis of proficiency in word recognition, and test these subjects in the word recognition paradigms discussed in Approach 4.1.

Program 4.3.4 Identification of the Differences between Good and Poor Readers with Respect to Processing Components.

The development of poor readers needs examination, not only for applying findings to assist in diagnosis and remediation, but also as a test of the generalizability of the model of the successful learner. We should systematically study differences in the use of information by poor and good readers under controlled conditions. The evidence from extensive studies of reading errors (Goodman, 1973) shows that children who are poor readers do not exploit the various sources of contextual and visual information in optimal proportions. In the middle grades, for instance, they seem to be grappling with word identification with only moderate success and at the expense of attention to syntactic and semantic constraints, especially when passages become difficult for them.

Program 4.3.5 Examination of Those Behaviors Observed in the Learner, But Not Generally Observed in Skilled Readers.

Decoding, which involves letter-sound generalizations and blending, occupies a major part of initial reading instruction and is acquired to some degree by all readers, regardless of their instructional programs (Venezky, 1974). Studies by Venezky and Johnson (1973) and by Venezky, Chapman, and Calfee (1972) have shown interesting developmental trends for certain letter-sound patterns, but have not attempted to uncover specific processes or structures to account for these data. We should examine the acquisition of letter-sound patterns, and in particular those which change over time, from an information-processing viewpoint.

APPROACH 4.4

DEVELOPMENT OF A MODEL FOR EYE-MOVEMENT GUIDANCE DURING READING

The movement of the eyes has been studied extensively since the latter part of the nineteenth century. Javal (1879) established that the eyes move in jerks or saccades, the information coming in only during the fixation pauses. Studies by Judd and Buswell (1922), Ballantine (1951), and Gilbert (1959) concerned the eye movements of readers of all ages reading material of different complexities. More recently computer-controlled eye-movement monitoring has led to renewed interest in measuring eye movements and in analyzing the ability of the reader to process information from different points in the visual array (McConkie and Rayner, 1974; Abrams and Zuber, 1972; Stern, 1974).

Models of reading must be concerned with the nature of the mechanism which guides the eye's movements in reading. To what extent are eye movements dependent upon visual information in the periphery and upon preceding semantic or syntactic information, and to what extent are they dependent on the physiological properties of the optical system?

Models of eye-movement control may be classified according to the extent current processing determines where the eyes move next (Hochberg, 1970; Bouma and de Voogd, 1974). Models that posit strict control of eye movements view reading as analogous to picture or scene scanning. As in picture processing, these models assume that the reader moves his eyes on the basis of what he has already seen and what looks interesting in peripheral vision. Another class of models, however, sees eye movements serving to place each word of the text in foveal vision for a brief period so that it may be seen clearly. Woodworth (1938) compared these eye movements to shoveling coal into a furnace at a relatively constant and fixed rate.

Models that assume that the eyes are guided voluntarily from fixation to fixation require experimental support for the following assumptions: (1) the eyes can be guided accurately to a particular location, (2) the information obtained in one eye fixation can be resolved soon enough to be used in determining the location of the next fixation, (3) the reader can resolve sufficient information from the periphery to locate succeeding fixation points, (4) the reader retains sufficient information about the visual properties of the text in order to guide regressive eye movements, and (5) the reader can both guide the eyes on the basis of what he has just read (and/or on the basis of what information is available in peripheral information) and simultaneously integrate the meaning of the word.

The issue of eye-movement control in reading is a good example of the consequences of lack of knowledge of a skill basic to reading. There have

been attempts to teach readers to move their eyes in a rhythmic manner, since work on eye movements seemed to indicate that skilled readers move their eyes at a fairly fixed rate. The failure of such programs led investigators to question the contribution of an understanding of eye movements to understanding reading (Tinker, 1958). However, viewing reading as a sequence of psychological processes demands a knowledge of how the reader guides his eyes in reading. Bouma's and de Voogd's (1974) success in testing whether strict control over eye guidance is a necessary component of normal reading illuminates the payoff potential on this issue. This approach should incorporate a number of experimental approaches and not be limited to the prototypical eye-movement paradigm. One can appreciate the advantages of converging operations here, especially because this area is a complex one, where paradigmatic artifacts frequently occur. Although many of these studies require the monitoring of eye movements in reading, they also require analysis of effects in isolation to assess processing limitations. For example, tachistoscopic studies employing partial report can define how much visual information can be resolved in a single eye fixation.

Program 4.4.1 Determination of How Accurately the Eyes Can Be Moved in a Saccade.

A guided eye-movement model assumes that readers can select a particular point in peripheral vision, such as the first letters of an as yet unidentified word, to fixate on. Similarly, in regressing to a misperceived word, the model assumes that readers can fixate their eyes accurately at that location. The central concern of this program is to determine how accurately readers move their eyes in a single saccade to a designated point. Accuracy should be determined over the entire vertical and horizontal range within a page of text. This project will establish an upper limit on eye-movement accuracy. Later programs will attempt to determine the degree to which readers utilize this capacity under different reading conditions.

Program 4.4.2 Determination of How Long Subjects Need to Integrate Visually Presented Information and Move Their Eyes on the Basis of that Information.

A typical experiment would present subjects with a visual field containing maximally discriminable forms offset from a fixation point. Then the researcher would present a directional signal at the fixation point and measure the accuracy and latency of the eye movement to the designated form.

Program 4.4.3 Determination of What Types of Information Can Be Resolved at Different Points in the Periphery.

The traditional approach to this problem has been the assessment of acuity as a function of retinal location, using isolated letters (Ruediger,

1907; Bouma, 1970) or letter strings (Woodworth, 1938; Bouma, 1973). Interference effects from adjacent letters have been studied by Korte (1923) and Bouma (1973). McConkie and Rayner (1974) have attempted to determine how well words, parts of words, and word shape can be resolved at different locations to the right of the fixation point. As in the previous program, experimental techniques should be used to establish recognition limits, employing the most direct methods possible. Then procedures should be devised to determine the degree to which readers utilize this capacity in reading. One experiment could use a partial report task for letter strings printed on a horizontal line (Sperling, 1970; Smith and Ramunas, 1971). In this task the visual display is followed by a report cue designating which letter to report. The research should determine accuracy of report as a function of the spatial location of the letter. Further studies should include manipulation of orthographic, syntactic, and semantic constraints in the letter strings. The results would delimit a functional visual field during an eye fixation.

Program 4.4.4 Determination of How Much Visual Information Can Be Resolved in the Periphery with Unlimited Processing Time.

In the typical study in this area subjects maintain their fixation and report everything they can from the periphery. Estes, Allmeyer, and Reder (in prep.) have employed this paradigm to study the loss of spatial information about letters in the periphery, and have shown that orthographic structure can help resolve letter position. Further work in this area should consider the influence of syntactic and semantic constraints in natural language on the amount of information which may be resolved in the periphery.

Program 4.4.5 Determination of How Much Information about the Spatial Properties of the Text Is Available to Readers for Guiding Regressive Movements.

This research question has been virtually ignored, yet guidance models assume that sufficient spatial information is available for guiding regressive movements not only on the same line but also on immediately preceding lines. A variety of methods of the nature described above should be attempted in this area, e.g., partial report.

Program 4.4.6 Determination of Whether, as the Guidance Model Assumes, Readers Can Resolve Meaning and Simultaneously Decide Where to Go Next.

Consider the task of readers who guide their eyes on the basis of what they have just read or what they see in peripheral vision. In the period of roughly 1/4 of a second, they must make the eye-movement decision and initiate the movement. We need experiments to test whether, in fact, the skilled reader and the beginning reader have the capacity to read in

this manner. Other experiments are necessary to determine how long it takes readers to notice something in peripheral vision and initiate an eye movement to that position. One possible paradigm might present subjects with a shape name in foveal vision with two different shapes at different places on the horizontal to the right. Their task would be to fixate on the shape designated by the shape name as quickly and as accurately as possible. Measures of eye movement latency and accuracy should establish boundaries on this ability.

APPROACH 4.5

MEASUREMENT OF THE INFORMATION-PROCESSING HABITS OF COMPETENT READERS WHEN THEY ARE CONFRONTED WITH COMPLEX READING TASKS

For light information loads, or for tasks in which readers are not concerned with complete or nearly complete processing of ideas or facts, reading may be composed of predominantly forward-going eye movements. However, the form of reading that appears to place the greatest processing demands upon readers is called, for lack of an agreed-upon label, careful reading. It is the process by which competent readers gain recallable information from a text. For the present, we assume that this process does not involve overt articulation, but may involve subvocalizations. As integration and recall demands increase, readers move backward and forward, taking in new materials and returning to previously scanned parts as they discover that they need to reexamine them. This form of reading probably predominates for almost all subject matter children encounter in their schooling and is especially true for materials presenting a high conceptual load to readers of any age.

Forward-going (single pass) reading, with only occasional regressions is characteristic of the popular notion of reading, and is also the type of reading that most instructional programs strive for. Timed comprehension tests, for example, implicitly demand regressionless reading, yet it may be that the amount of information gained in this manner is far below that presented to children by most school books or to adults in more complex texts. It is interesting to note that most eye-movement research, due in part to difficulties in tracking vertical movements, ignores careful reading. We do not even have an adequate term for the rereading of words or phrases when the rereading is not due to immediate recognition-integration problems (i.e., is not a regression).

Careful reading is probably atypical; most adults probably do not read for high recall and therefore can afford the luxury of a predominantly forward-going process.

Skimming, directed search, and of course the predominantly forward-going reading which characterizes the reading of light novels and news articles are directly related to careful reading, but how they differ from it remains to be explored. One hypothesis is that rapid skimming, careful reading, and most other observed forms of reading behavior differ only in quantitative ways, that is, in the relative amounts of types of information utilized at each processing stage. For example, skimming might use more syntactic or semantic information for word recognition than does deliberate reading, while the latter might rely predominantly upon visual cues (e.g., letter shape, word shape, etc.) for the same process. The opposing hypothesis is that the processes differ in qualitative ways.

Program 4.5.1 Development of a Measure of Information Load for Short Texts.

In order to carry out studies which vary information load we need to develop procedures and a metric for scaling texts on this dimension. Much previous work on the readability of text exists and might be useful here. We should also consider approaches to assessing the redundancy of text, the ratio of familiar to unfamiliar words in the text, and the importance of syntactical and contextual cues in the development of the measure.

Program 4.5.2 Development of Eye-Movement Tracking Procedures for Careful Reading.

The study of the underlying processes and strategies employed in careful reading will be hindered until we develop procedures for tracking eye movements in multipass reading behavior. These procedures should be applicable for a variety of text conditions of memory load and for varying recall criteria.

Program 4.5.3 Collection of Baseline Data on Silent Reading Rates for Careful Reading under Varying Information Load and Recall Conditions and for Extent of Recall for Single Pass Reading under Conditions of Varying Information Load.

Such data would be very informative for interpreting studies of differences between the processes involved in careful and single pass reading.

Program 4.5.4 Measurement of Reading Behavior for Texts of Varying Information Load and for Varying Required Recall Criteria.

Descriptive studies of careful reading using the information load measure (Program 4.5.1) and the eye-movement tracking procedures developed in Program 4.5.2 are necessary before we may determine how careful reading behavior differs from single pass reading. Once we gather this information we may contrast it with new or existing data on single pass reading. Such a comparison might help to resolve the issue of whether the differences are quantitative or qualitative. Another strategy for getting at the same issue might be to vary recall requirements for careful reading until the demands on the reader reduce to those ordinarily satisfied by single pass reading. The changes in reading behavior in response to the gradual reduction in recall requirements should indicate the nature of changes in the processes. Still another procedure might entail starting out with recall demands which may be met by single pass reading, and gradually increasing the recall demands until multiple passes are required.

Program 4.5.5 Determination of the Accuracy with Which Readers Can Return to Previously Read Materials in the Immediate Reading Task.

The process of skilled careful reading requires a reader to be able to identify the physical location of a fact or idea within a short text, given prior information for such location recall (Rothkopf, 1971). Yet little information exists about the accuracy with which readers can carry out this task or how accuracy varies with the complexity of the material and the degree to which readers recall the particular item (e.g., is location recall for "forgotten" items any better or worse than location recall for remembered items?). Beyond simply assessing accuracy, knowledge of the strategies careful readers employ for relocating facts or ideas within text seems important both for understanding reading and for instructional purposes. Studies directed at these issues will require tracking eye movements of careful readers in controlled conditions.

Program 4.5.6 Determination of the Effect on Accuracy of Recalling Nonverbal Information in a Text.

A companion set of studies to Program 4.5.5 which could aid the development of readable text would involve the measurement of accuracy of recall for textual variations in graphical information (e.g., whether or not numbers were present verbally or as numerals; which work was in italics) and in page configuration, especially when tables, figures, pictures, and varying column formats are used.

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